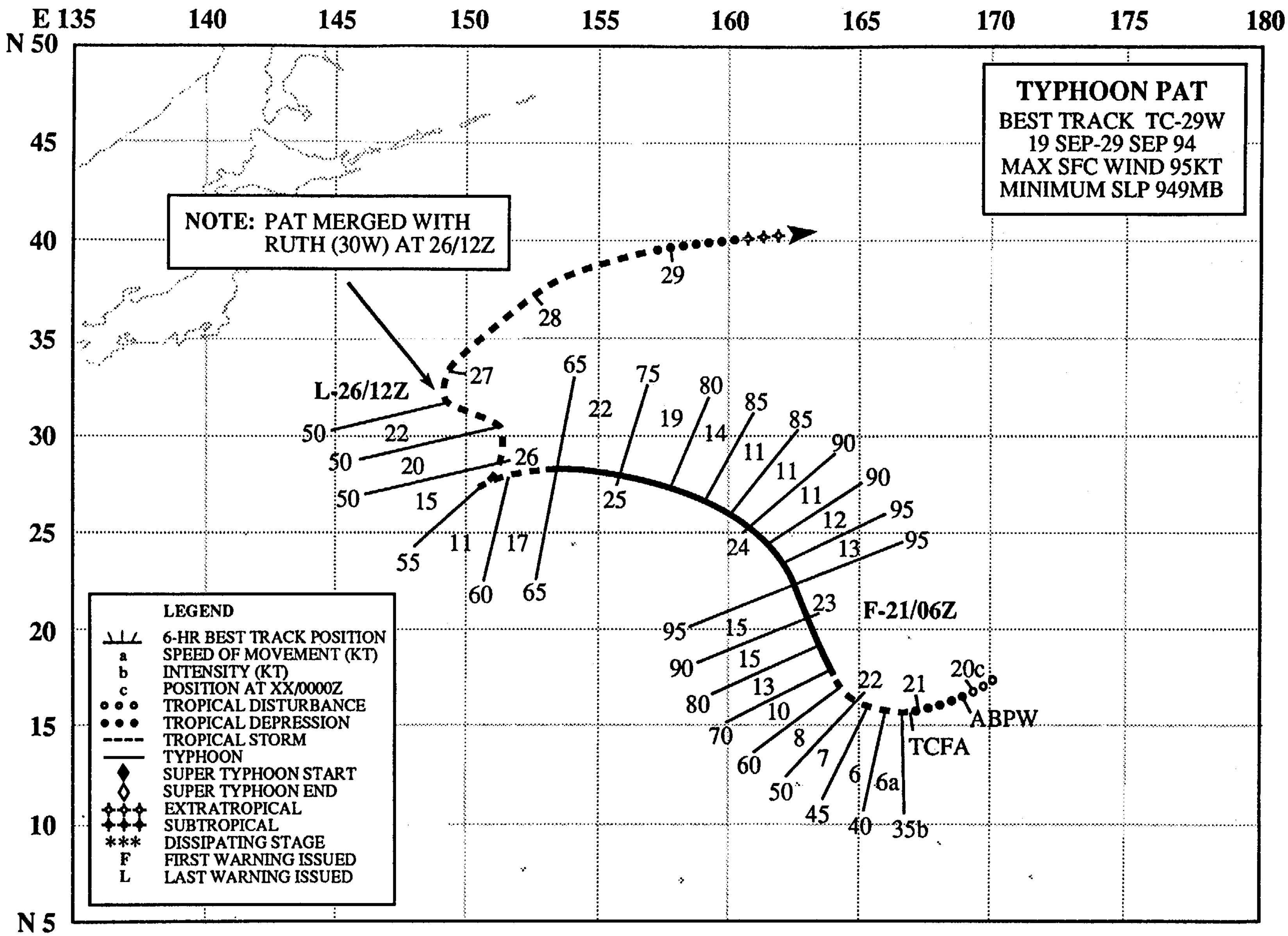
TYPHOON PAT
BEST TRACK TC-29W
19 SEP-29 SEP 94
MAX SFC WIND 95KT
MINIMUM SLP 949MB
NOTE: PAT MERGED WITH RUTH (30W) AT 26/12Z
L-26/12Z
F-21/06Z
TCFA
ABPW
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 135
140
145
150
155
160
165
170
175
180
N 50
45
40
35
30
25
20
15
10
N 5

TYPHOON PAT (29W)

I. HIGHLIGHTS

The symmetrical collapse of deep convection during the merger of Pat with Tropical Storm Ruth (30W) is the first documented case of such an event. Pat developed at the extreme eastern terminus of a reverse-oriented monsoon trough. Pat's overall track pattern was an unusual north-oriented "S" shape that included a period of rapid counter-clockwise mutual orbit with Ruth (30W). Pat was a small typhoon.

II. TRACK AND INTENSITY

During the latter half of September, the circulation of the western North Pacific was dominated by an active monsoon trough. The low-level southwesterly winds associated with this trough had extended far to the north and east of normal, and the axis of this monsoon trough had a SW-NE (i.e., reverse) orientation. All of the tropical cyclones which formed in association with it — Melissa (26W), Nat (27W), Orchid (28W), Pat and Ruth (30W) — moved on north-oriented, "S"-shaped, tracks.

The tropical disturbance which became Typhoon Pat, was first observed at the far eastern reaches of the monsoon trough. It was listed as a suspect area on the 200600Z September Significant Tropical Weather Advisory when synoptic data and satellite imagery indicated that a low-level circulation center (with deep convection sheared to its southeast) had formed near Wake Island. An increase in the amount and organization of deep convection associated with this system prompted the JTWC to issue a Tropical Cyclone Formation Alert at 210400Z. The first warning followed at 210600Z.

Initially moving slowly west-southwestward, Pat turned toward the north-northwest and intensified. At 230000Z, when located about 270 nm (500 km) northwest of Wake Island, Pat reached 90 kt (46 m/sec) (Figure 3-29-1). It reached its peak intensity of 95 kt (48 m/sec) at 230600Z and began to weaken after 231200Z. At 240000Z, the system began to take a more westward course as it entered a easterly steering regime between a strong ridge to its north and another tropical cyclone — Tropical Storm Ruth (30W) — to its southwest. At 241200Z, Pat and Ruth (30W) abruptly increased their rate of centroid-relative cyclonic orbit. At 261200Z, the two tropical cyclones merged into a single vortex. The merged Pat and Ruth then recurved, and the final warning was issued at 281200Z. Post-analysis of synoptic data and satellite imagery indicated that the system most probably was a minimal tropical storm until 281800Z and a tropical depression until 291200Z.

III. DISCUSSION

The interaction of two adjacent tropical cyclones is often referred to as the Fujiwhara effect after the pioneering laboratory and observational studies of Fujiwhara (1921, 1923, and 1931). Fujiwhara demonstrated that the relative motion of two adjacent cyclonic vortices was composed of cyclonic orbit around their centroid, coupled with a mutual attraction. The rate of orbit steadily increases as the vortices spiral inward toward one another and eventually the two vortices coalesce into one vortex located at the centroid.

Usually the behavior of two adjacent tropical cyclones differs from the classical Fujiwhara effect in several aspects; prominent among these is the usual failure of tropical cyclones to merge. Because of these differences, the interaction between two tropical cyclones is usually called binary interaction. Dong and Neumann (1983) studied the behavior of interacting tropical cyclones and defined binary interaction as the occurrence of two named tropical cyclones which co-exist for at least 48 hours during

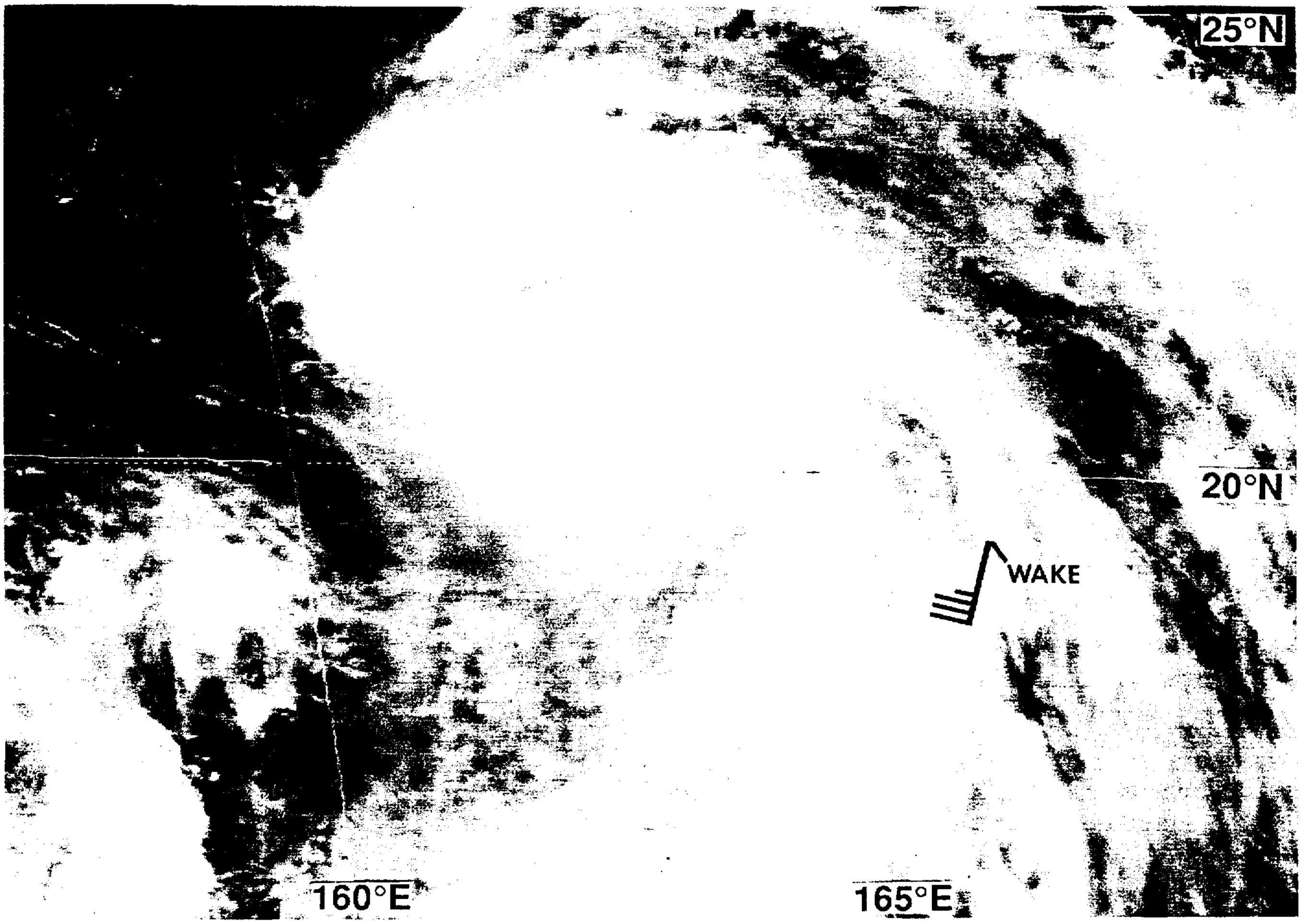

Figure 3-29-1 Pat at 90 kt (46 m/sec) six hours before its peak intensity of 95 kt (48 m/sec). The 230000Z gradient-level wind at Wake Island (WMO 91245) is plotted (230031Z September GMS visible imagery).

which time they approach within at least 780 nm (1450 km) and reach at least tropical storm intensity. The separation criterion was based on other studies by Brand (1970), which showed that mutual cyclonic orbit tends to dominate when storms approach within this distance. Brand further noted that mutual orbit tends to commence suddenly. Lander and Holland (1993) developed a generalized model of binary interaction (Figure 3-29-2), and showed that the classical Fujiwhara model of converging cyclonic rotation about a centroid followed by merger is rarely observed.

In all previously known cases of tropical cyclone merger, only one of the tropical cyclones experiences a loss of deep convection, followed by strong horizontal shearing and incorporation into the circulation of the surviving tropical cyclone. Prior to the interaction between Pat and Ruth, the symmetrical collapse of the deep convection of both tropical cyclones as they merge into a single vortex had not been documented (Lander 1995b).

During the last week of September, the tropical atmosphere over the western North Pacific Ocean was dominated by a very active monsoon trough. At the time of the satellite imagery in figure 3-29-3, two named tropical cyclones had formed in the monsoon cloud band — Orchid (28W) and Pat. A tropical depression (30W) (that later became Tropical Storm Ruth) was located between these two named storms. Over the next two days, Pat moved rapidly northwestward, and the tropical depression (30W) between Pat and Orchid (28W) was upgraded to Tropical Storm Ruth. Ruth (30W) initially moved northeastward and rapidly approached Pat. Over a 22-hour period, 250230Z to 260030Z, Pat and Ruth

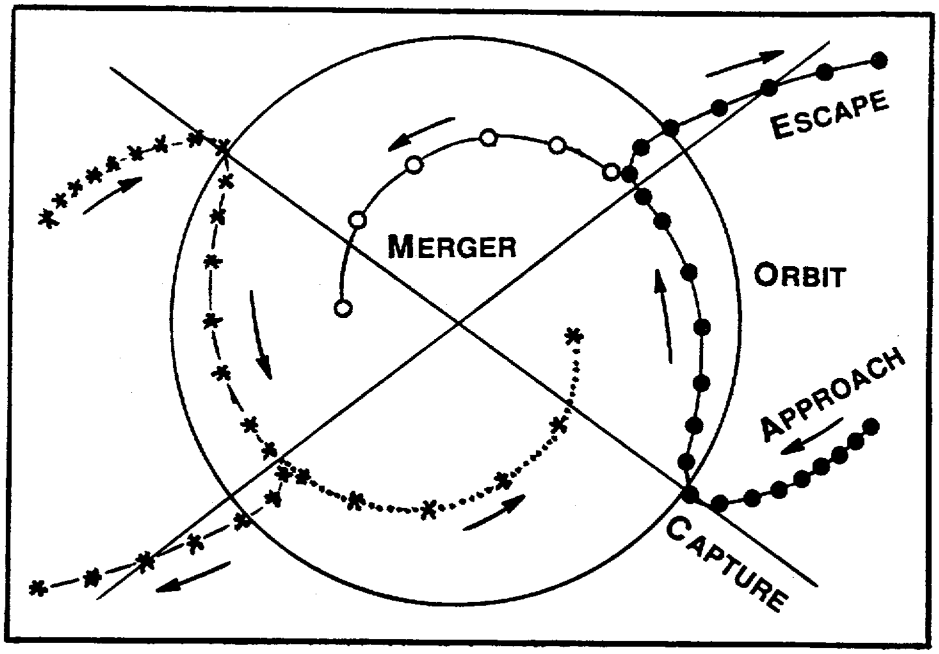

Figure 3-29-2 Model of binary interaction of two tropical cyclones containing the major elements of approach and capture, followed by mutual orbit, then escape or merger (from Lander and Holland 1993).

(30W) approached to within 200 nm (370 km) (Figure 3-29-4) and underwent about 180° of cyclonic orbit relative to their centroid (Figure 3-29-5a,b). The orbit continued during the night (260600Z to 261800Z), and during this period both systems lost their central convection and merged to become one vortex by the next morning (262330Z) (Figure 3-29-6).

At first, the merged vortex lacked significant central convection, but it still possessed tropical-storm intensity wind. The merged vortex (designated by the JTWC as Ruth) regained central convection within 24 hours following the merger (Figure 3-29-7). Later, Ruth (i.e., the merged Pat and Ruth) recurved into midlatitudes and decayed.

IV. IMPACT

No reports of significant damage or fatalities were received.

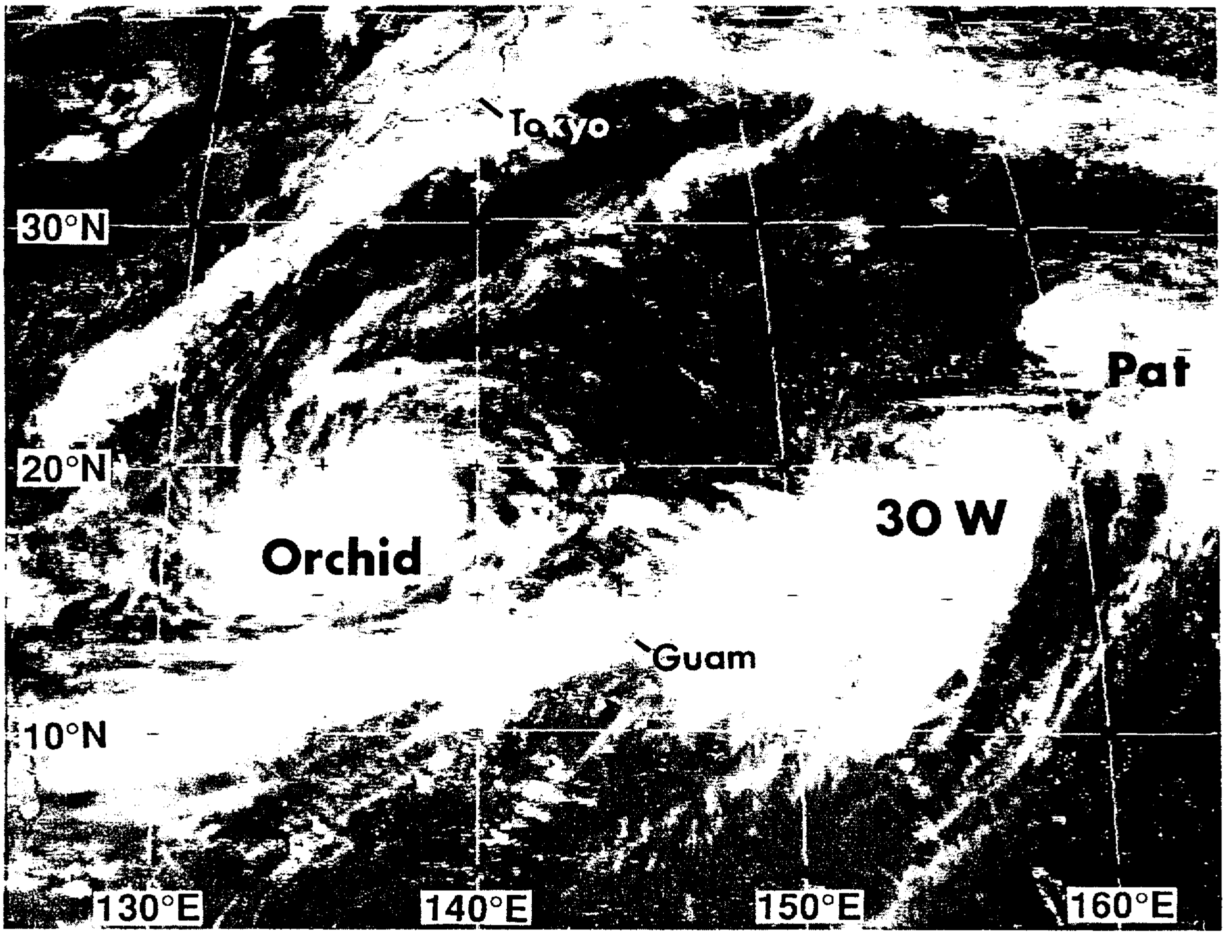

Figure 3-29-3 An active reverse-oriented monsoon trough. Typhoon Orchid, Tropical Depression 30W (later becoming Ruth), and Typhoon Pat are indicated (240031Z September GMS visible imagery).

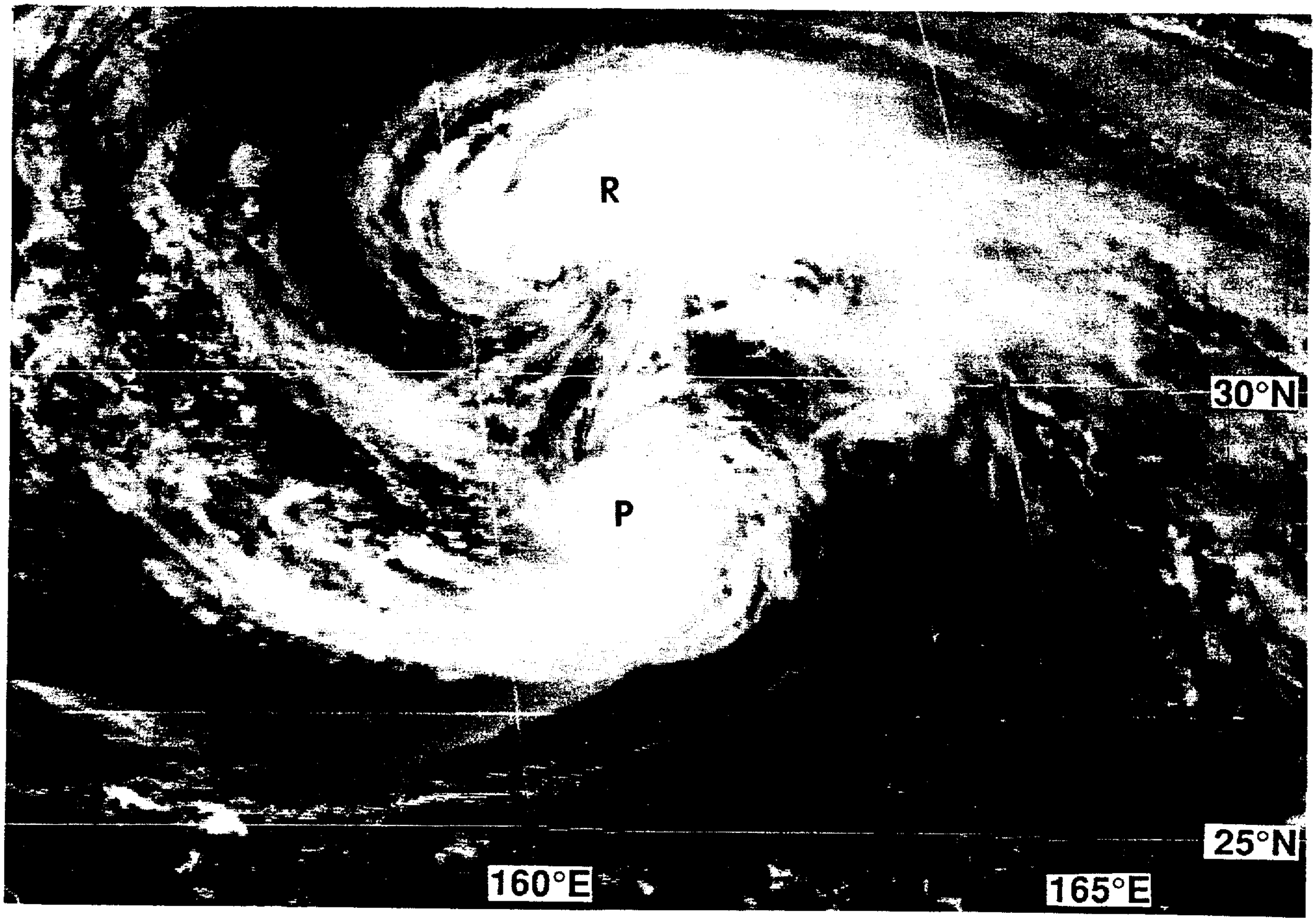

Figure 3-29-4 Pat and Ruth (30W) have moved to within 200 nm (370 km) of one another (260131Z September GMS visible imagery).

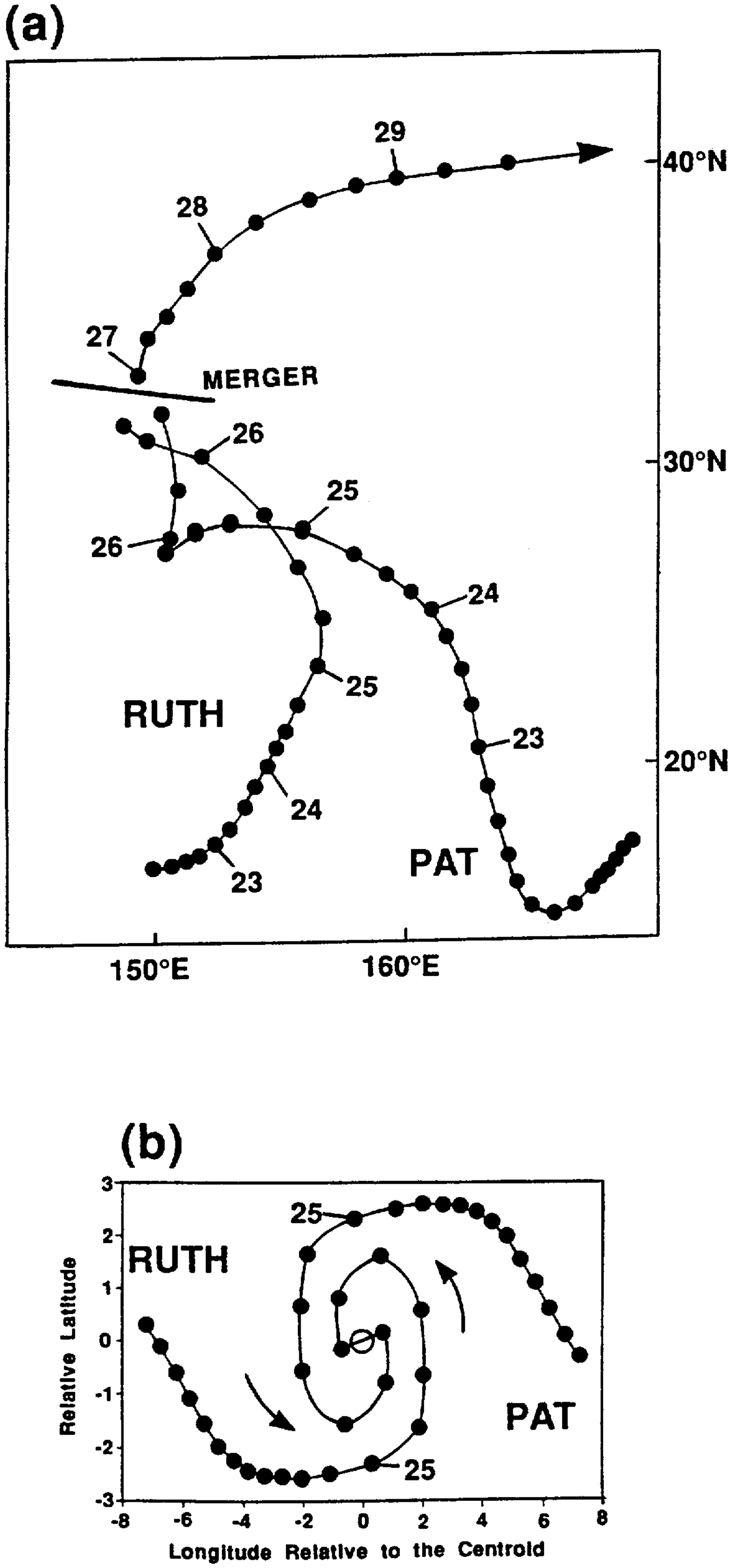

Figure 3-29-5 The tracks of Pat and Ruth (30W) in two reference frames: (a) Earth-relative [Black dots are at six-hour intervals. The positions at 0000Z are indicated. The merger location is shown as a solid bar, after which the two tracks become one], and (b) Centroid-relative [Black dots are at six-hour intervals. Positions at 250000Z September are indicated. The open circle is the centroid, where merger takes place shortly after 261200Z September]. (Adapted from Lander, 1995b).

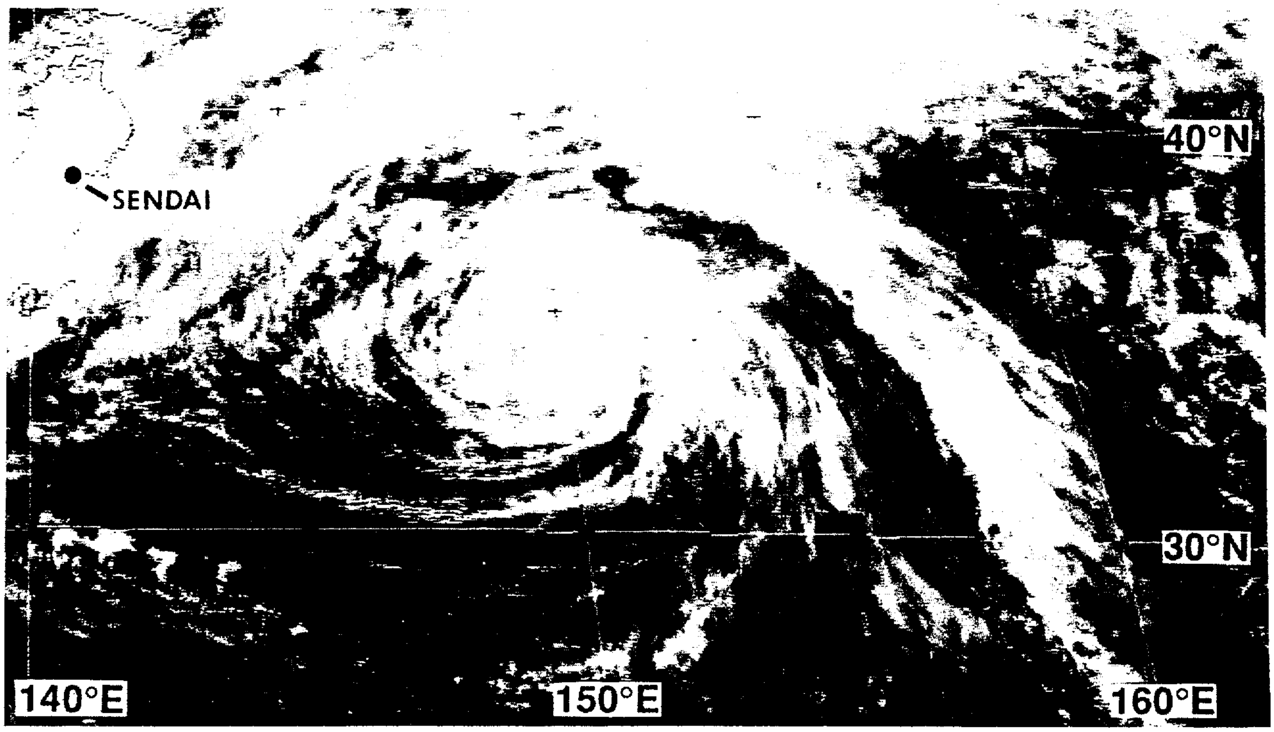

Figure 3-29-6 The single vortex that is the merged Pat and Ruth (30W). Deep central convection is absent, but ship reports and tightly wound low-level cloud lines support surface winds of tropical storm intensity (270031Z September visible GMS imagery).

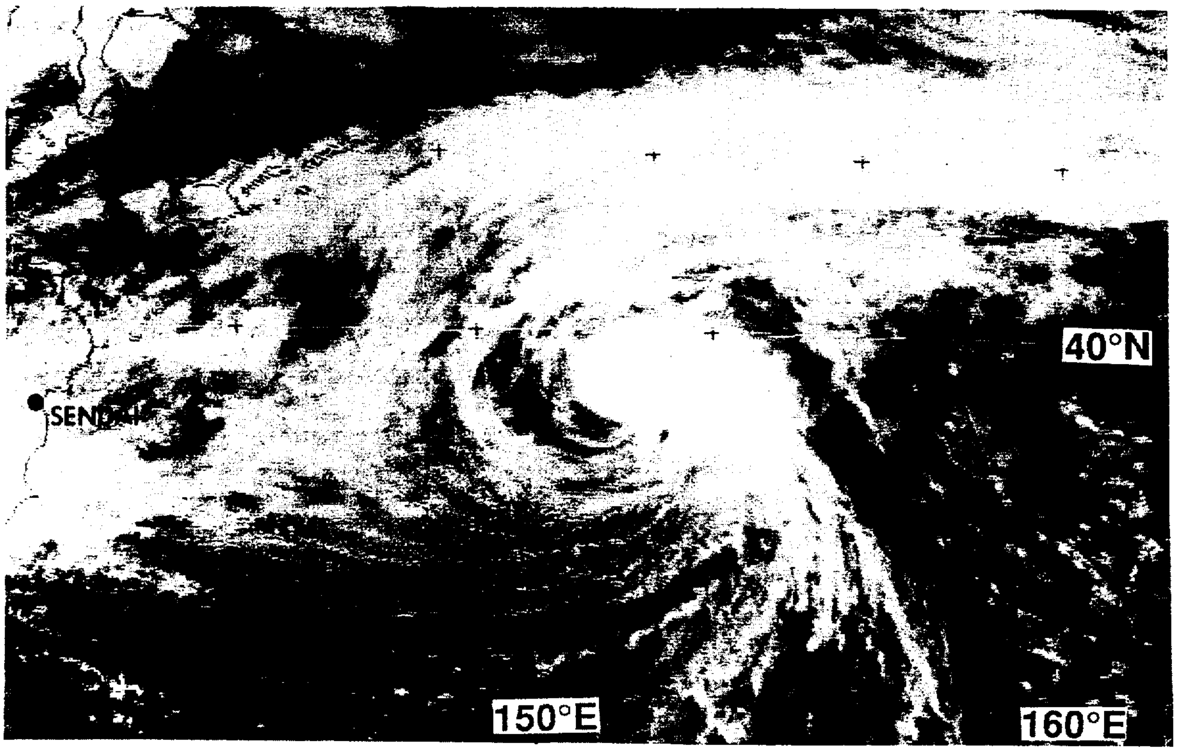

Figure 3-29-7 Central deep convection has been re-established as the merged Pat and Ruth begins its recurvature into midlatitudes (280031Z September visible GMS imagery).